CHAPTER 1 - INTRODUCTION TO FLOOD PROOFING

Flood proofing can be defined as "any combination of structural or nonstructural changes or adjustments incorporated in the design, construction, or alteration of individual structures or properties that will reduce flood damages." Simply stated, flood proofing includes any effort property owners may take to reduce flood damage to individual structures and their contents.

FLOOD PROOFING OBJECTIVES

FLOOD DAMAGE REDUCTION. The potential for flood damage is determined by the depth and velocity of flooding and the number of times a structure and its contents may be flooded. Flood proofing a structure will decrease the potential for damage from future floods. Without flood proofing, a structure is subject to damage from all floods that enter the basement or rise above the first-floor level.

Flood proofing can benefit the property owner in several ways. It will save money that would otherwise be spent to repair and clean up the structure and its contents after a flood. In some cases, much or all of the contents, as well as the structure itself, are destroyed. Also, flood proofing will reduce the inconvenience and annoyance caused by the time-consuming process of cleaning up and repairing a structure. Other benefits of flood proofing may include less time off work due to flooding, improved health and safety, peace of mind knowing the frequency of flooding is reduced, and other intangible benefits.

EFFECTIVENESS. All flood proofing measures can be effective in reducing damages from floods for which the measure was designed. However, the only way to ensure complete safety from flood damage is relocating the structure to a site outside of the flood plain. When structures are not removed from the flood plain, floodwaters may rise to an elevation that overcomes any flood proofing measures-- possibly causing damages equal to or perhaps even greater than what would have been caused without flood proofing, unless the flood proofing measure used is elevation. Unless a structure is relocated out of the flood plain, the structure will still be exposed to some potential flood damage even if flood proofed.

SAFETY. Even after flood proofing, a structure in a flood-prone location will still be subject to flooding if floodwaters exceed the design level or cause failure of the flood proofing measures. Property owners must keep this in mind to avoid a false sense of security. No one should remain in a flood proofed structure during a flood, as the flooding could be hazardous and life threatening. High-velocity flows, waves, or other conditions can cause floodwaters to suddenly cause the flood proofing measure to fail, leaving occupants little or no time or ability to vacate the structure and flooded areas. In addition, rising floodwaters may inundate all overland means of escape.

FLOOD PROOFING MEASURES

Flood proofing measures either reduce the number of times the structure is flooded or limit the potential damage to the structure and its contents when it is flooded. There are four general approaches to flood proofing:

- Elevating the structure
- Relocating the structure
- Constructing barriers such as floodwalls or levees to stop floodwaters from damaging the structure
- Modifying the structure through flood proofing and relocating contents to minimize flood damage.

ELEVATION. Elevation involves raising such structures as buildings in place so that the lowest floor is above the flood level for which flood proofing protection is designed. The building is raised and set on a new or extended foundation.

Almost any structurally sound building can be elevated. Typically, the least expensive and easiest structure to elevate is a one-story frame building built over a crawl space that is at least 18 inches in height. The process becomes more difficult and expensive as different structures are considered, such as a building with a basement, a slab-on-grade building, a building constructed of brick or block, a multi-story building, or a building with additions.

Property owners wishing to use this method should employ a contractor to ensure that the building is properly raised and a safe foundation is constructed. The elevated foundation must be able to withstand erosion caused by floodwaters, the impact caused by ice and debris in floodwaters, hydrostatic and hydrodynamic force, and impact from high wind velocity and earthquake events. It is also advisable to have the building inspected by a structural engineer prior to elevation to assess the structure’s ability to undergo elevation.

Buildings can be elevated on basically two different types of foundations--an open foundation and a closed foundation. Elevating a building on an open foundation involves raising it onto piers, posts (columns), or piles. If the building is located in an area of coastal flooding, an open foundation is the only way to safely elevate. If the building is subject to high-velocity riverine floodwaters, significant water depths, or potential erosion, the property owner should also consider having the building elevated on an open foundation. Doing so will allow the waters to flow beneath the building and reduce potential damaging impacts. Selection of the proper open foundation (piers, posts, or piles) for various flooding and site characteristics is critical to success. Elevating a building on a closed foundation involves raising it on extended foundation walls or on fill. Elevating on extended foundation walls is very effective where floodwater velocities are low and erosion potential is also low. Elevating on fill is very effective in almost any situation.

<u>Elevation on Extended Foundation Walls</u>. Elevation on extended foundation walls is normally used in areas of low to moderate water depth and velocity. After the building is raised, existing foundation walls can be extended vertically using materials such as masonry block or poured concrete. The building is then set down on the extended walls. While elevating a building on extended foundation walls is often the easiest solution to the problem of flooding, there are several important considerations. The most important concern is that the original foundation and footings must be able to withstand the extra loading, not only from the additional vertical dead load of the new wall but also from the additional flood forces from floodwater against the foundation and from wind forces against the elevated building. If the footings are not deep and wide enough, they may be unable to resist the additional loads, which could result in overturning or undermining of the walls and subsequent collapse. In addition, the original foundation walls may not be wide enough to be extended. A structural or foundation engineer should be consulted to make these determinations.

Depending on the potential flood forces, it will be necessary to reinforce both the footings and the walls using steel reinforcing bars. An equally important concern regarding new foundation wall construction is how it is connected to the existing superstructure of the building. Regardless of what type of extended foundation wall construction is used, hydrostatic and hydrodynamic forces can result in collapse of the structure support system. To eliminate the risk of damage due to hydrostatic force, extended foundation walls need to be constructed with openings or vents to allow floodwaters to enter the enclosed area and equalize the hydrostatic force.

A potential solution to the problem of excessive hydrodynamic force on extended foundation walls is to elevate the building on only two walls, spanning the building between them and leaving the two ends open. By orienting the walls parallel to the flow of water, the amount of wall area resisting the forces from floodwater velocity is less, and loading is significantly reduced. In many cases, the ends are not left totally open. For esthetic or security reasons, it may be desirable to enclose the area. This can be accomplished by installing lattice work or lightweight walls that are designed to break off during floods.

<u>Elevation on Piers</u>. An open foundation support structure is the pier. The piers normally used in flood proofing applications differ from those used in bridge support applications in that a pier for flood proofing consists basically of an upright support member tied to and supported by a reinforced concrete spread footing. This design allows the individual pier to resist lateral movement without the need for cross bracing between the posts as is sometimes needed in a pure post or column design. While they may be the most commonly used type of open foundation for elevating existing structures, they are the least suited for withstanding lateral flood and wind forces. In conventional use, piers are designed primarily for vertical loading. When exposed to flooding, however, they will also experience hydrodynamic forces. Piers used in flood proofing to support an elevated building must be substantial enough to support the structure and also sufficiently reinforced to resist a range of flood and wind forces.

Piers supported by reinforced concrete footings are generally used in shallow-depth flooding conditions with low-velocity flow where scour is not a problem. Piers are normally constructed of either masonry block or poured-in-place concrete. They must have steel reinforcing both in the pier itself and in the footings providing support; the steel reinforcing must be tied together to prevent separation. There must also be a suitable connection between the superstructure and the piers to resist wind and buoyancy forces.

Elevation on Posts or Columns. When flooding is characterized by moderate depths and velocities, elevation of structures on posts (also referred to as columns) is a frequently used flood proofing method. Posts are made of wood, steel, masonry, or precast reinforced concrete. Their ends are set into pre-dug holes, and material such as earth, gravel, crushed stone, or concrete is backfilled around them. Since substantial loading is usually expected, posts are normally anchored into a concrete pad at the bottom of the hole. Care must be taken to ensure that the posts or columns are embedded deeper than any expected scour depth.

While piers are designed to act as individual support units, posts normally must be braced for an additional factor of safety. A variety of bracing techniques, using several different materials, exists. The type to be specifically employed on an elevated structure in a particular area depends on local flood conditions and loads. Some of the more commonly used bracing techniques include wood knee and cross bracing, steel rods, and guy wires.

Elevation on Piles. Where high-velocity flooding can result in scouring, piles provide the best type of foundation. Piles differ from posts in that piles generally are mechanically driven into the ground usually to depths greater than that for posts. Because of this, piles are less susceptible to the effects of high-velocity floodwaters and scouring. Piles must either rest on a support layer, such as bedrock, or be driven deep enough so there is enough friction between the pile and the surrounding soil to carry the load. Piles are generally made of wood, steel, or reinforced precast concrete. They may require bracing similar to the methods described for posts. Because driving piles generally requires bulky machinery, an existing structure that is being flood proofed will have to be temporarily moved aside and set on cribbing until the driving of piles is complete.

Elevation on Fill. This measure is widely adaptable to be successful in almost any situation. The greatest concerns with this measure are erosion of the earthen fill material and settlement of the earthen fill material. The erosion potential can normally be corrected by erosion protection such as riprap. Settlement of the earthen material can be a problem if the structure foundation rests directly on the fill material such as with a slab-on-grade. If this type of foundation is used, an existing structure must be moved to the side temporarily so the fill material can be properly compacted. The best use of this measure is to elevate the structure on extended foundation walls and then place earthen fill material directly against the extended foundation walls. This reduces problems that a stand alone extended foundation wall has such a hydrostatic force, hydrodynamic force, and ice and debris flows.

RELOCATION. Relocating a structure is the most dependable way to flood proof. This method involves moving the structure to another location away from flood hazards. It is the ultimate option for the property owner who wants to be free from the damages, fear, and worry associated with flooding.

This procedure involves raising the structure (e.g., a building), as described in the previous section on "elevation," and placing it on wheels. The building is then transported to a new location and placed on a new foundation.

Property owners should consider many factors before deciding to relocate, including the building's structural soundness and whether there are bridges or other obstructions along the transportation route. During the move of a residential structure, property owners and their families must live elsewhere, perhaps for several weeks, and may need to store furniture and belongings temporarily.

Normally, cost is the major concern associated with building relocation. In addition to paying the moving contractor, the property owner may need to purchase a new lot, build a new foundation, relocate utilities, landscape, and pay for professional services and fees.

FLOODWALLS AND LEVEES (WITH/WITHOUT CLOSURES). Floodwalls and levees are located away from the structure to be protected and prevent the encroachment of floodwaters. They may completely surround the structure or protect only the low side of the property. Unlike other flood proofing measures, a well-designed and constructed freestanding floodwall or levee results in no floodwater forces on the structure itself. Consequently, as long as the floodwall or levee is not overtopped or otherwise failed, the structure is not exposed to damaging hydrostatic or hydrodynamic forces. With these kinds of measures, there is no need to make structural alterations to the building or structure to be protected. These measures require installation of a sump pump to enable seepage water flowing through or under the levee or floodwall, and rainwater falling inside the levee or floodwall, to be evacuated prior to damaging the protected structure.

Floodwalls and levees require periodic maintenance, including the removal of debris from any check valves on pump discharge pipes after each storm and inspection of the sump pump for proper operation. In addition, the property owner will need to inspect levees for signs of erosion, settlement, animal burrows, and trees. Floodwalls need inspection for signs of cracking and spalling. Care must be taken when constructing floodwalls and levees to protect other properties from any adverse impacts, to avoid filling in wetlands, and to maintain regulatory floodways.

While it is possible to design floodwalls and levees for large flood forces associated with major flood protection projects, such flood proofing measures for individual structures are generally restricted to a height of 6 feet or less. This restriction is usually necessary because of limited space, cost, visual concerns, and less complex design analysis.

The most important consideration of all is that property owners who have constructed floodwalls or levees should not have a false sense of security about their property protection. Every flood is different and one that exceeds the design height and overtops the floodwall or levee or breaches the floodwall or levee can happen at anytime. For this reason, the protected area should always be evacuated prior to flooding.

If a floodwall or levee fails due to overtopping, damage to the protected structure will be as great or greater than if no protection had been provided. Additional damage could even result because of the longer time it takes to remove floodwater from the inside of the floodwall or levee once flood levels subside.

Levees. Typically, levees are constructed of compacted fill taken from locally available soils. Depending on the availability of suitable local soils, levees may be one of the least expensive of all flood proofing measures. They are usually built parallel to the river and extend to high ground when it is available. They can also be built to completely surround the structure to be protected. Because they are easy to shape, levees can be made compatible with the landscape. If enough space is available, they can have broad bases and rounded tops to blend in with the surrounding landscape. The property owner can plant grass and other forms of light vegetation on an earthen levee to help prevent erosion and provide esthetic enhancement. Compacted earth can also be placed against a building in lieu of a free-standing levee and pleasingly landscaped. This could be considered a dry flood proofing technique.

Levees have drawbacks that may make them impractical for many property owners. One potential problem is that levees can impede the natural flow of water in a flood plain, possibly resulting in increased flooding of adjacent property. Similarly, they can also block the natural drainage from surrounding property. Another major drawback is that levees take up a considerable amount of property space. To minimize erosion and to provide adequate stability, their embankment slopes must be no steeper than a ratio of one vertical to two horizontal--with a ratio of one vertical to three horizontal preferred. Because of this, a levee’s width will be several times its height.

An important factor in determining the feasibility of a levee involves the availability of suitable fill material for the levee as well as the adequacy of the underlying soil that must support the levee. Most types of soils are suitable for constructing levees. The exceptions are very wet, fine-grained, or highly organic soils. The best soils are those that have a high clay content and therefore are highly impervious. Impervious soils minimize seepage problems either through or under the levee system.

In those cases where suitable fill material is not locally available, the expense of transporting appropriate material to the site can be significant. This additional cost could be a major factor in determining the economic feasibility of this measure. While all levee slopes should have vegetative cover, one way to further protect a levee from erosion is to armor the vulnerable areas with resistant material such as stone riprap.

Floodwalls. Similar to levees, floodwalls also keep water away from the structure being protected. However, floodwalls are constructed of stronger materials and take less space. Floodwalls can be constructed using a variety of designs and materials and can be constructed not only to protect a building but also to enhance its appearance.

Selection of a floodwall design is primarily dependent on the type of flooding expected at the structure site. Large flood depths and high flood velocities create large hydrostatic and hydrodynamic forces that could cause a floodwall to fail by tipping over. High flood velocities, combined with erosive soil, can also cause floodwall failure due to scour beneath the footings of the floodwall.

Closures. Closures must be provided for sidewalks, driveways, and other openings left in a floodwall or levee. However, floodwalls and levees designed without closures are more reliable because there is no need for human intervention to properly install the closure device in the openings. In the case of a levee, access may be provided simply by constructing the levee with gentler sideslopes at the driveway to allow vehicles to enter and exit by passing over the levee. When constructing a floodwall or levee around a structure, a sump pump must be incorporated into the design to provide proper interior drainage of floodwater seepage under or through the levee or floodwall and of rainwater falling on the protected side of the levee or floodwall.

Closures serve to close the openings in floodwalls and levees and prevent water from entering. They can consist of a variety of shapes, sizes, and materials. In some cases, closures are permanently attached using hinges so they can remain open when there is no flood threat. They may also be portable, normally stored in a convenient, nearby location and slipped into place when a flood threatens. There are a number of elements involved in designing and using a closure system. Closures can be separated into two basic categories: permanent or temporary. Combinations of permanent and temporary closures may also be feasible. Permanent closures are those that permanently close openings such as little-used doorways or windows. Temporary closures are those that are put into position to close an opening during a flood event and are then removed and stored away after the event.

Temporary closures can be considered an option only if a flooding situation provides sufficient warning time to properly install them. Both sufficient warning time and “human intervention” are critical to the success of closures since all temporary closure systems require personnel to install them and make certain they are properly sealed.

Closures that are stored between floods must be readily accessible. The effectiveness of an entire system will be compromised if the closures are stored such that flooding renders them inaccessible or if even one closure is improperly installed. Closure systems are most effective where there are a limited number of openings. If there are too many, leakage could overwhelm and defeat the system. Any sewers or drain pipes passing through or under a floodwall or levee will require closure valves to prevent backup and flooding inside the protected area. Care must also be taken to ensure that backfill material placed to cover utility access under or through a levee or floodwall is properly compacted so floodwater cannot breach the levee or floodwall.

DRY FLOOD PROOFING. Dry flood proofing involves sealing the walls of structures such as buildings with waterproofing compounds, impermeable sheeting, or other materials and using closures for covering and protecting openings from floodwaters. In areas of shallow, low-velocity flooding, closures in the form of shields can be used on doors, windows, vents, and other building openings. The first step in using closures placed directly on buildings is to be certain that both the closure and the building are strong enough and sufficiently watertight to withstand flood forces. To prevent backup and flooding inside a building, sewer lines should be fitted with cutoff or check valves that close when floodwaters rise in the sewer. Utility lines through the flood proofing measure also need to be designed so floodwaters cannot fail the flood proofing measure by following the utility line into the protected area.

Dry flood proofing is not generally recommended for buildings with basements. These types of structures are susceptible to large amounts of hydrostatic force if the ground surrounding the basement becomes saturated with water. This can result in serious damage to the structure due to uplift of the basement floor, collapse of the basement walls, or the entire structure becoming buoyant. Generally, dry flood proofing should only be employed on structures constructed of reinforced concrete, concrete block, or brick veneer on a wood frame. Weaker construction materials will fail at lower water depths from hydrostatic force. Conventionally constructed brick veneer on a wood frame or concrete block walls should not be flood proofed above a height of 3 feet because of the danger of structural failure from hydrostatic forces. Dry flood proofing above this height is not recommended unless the building walls are designed for larger hydrostatic force.

Some waterproofing compounds cannot withstand significant water pressure or may deteriorate over time. For effective dry flood proofing, a good drainage system must be provided to collect the water that leaks through the sealant or sheeting and around the closures to the interior of the structure. These systems can range from small wet-vacuums to a group of collection drains running to a central point from which water is removed by a sump pump. A perimeter drainage system leading to an adequate sump pump or pumps must be installed if an effort is made to flood proof a basement. This is needed in order to reduce hydrostatic force on the basement floor and walls. Property owners considering dry flood proofing should consult a professional engineer to analyze hydrostatic force that can cause structural damage to walls and floors. Though dry flood proofing may seem simple, it is a sophisticated method that requires full understanding of the possible dangers stemming from poor planning, design, or installation. Because it may be difficult to reliably evacuate seepage water and also to refrain from occupying a building during a flood event, this measure may be less easy to satisfactorily accomplish.

Most wall materials, except for some types of high-quality concrete, will leak unless special construction techniques are used. These techniques require a high level of workmanship if they are to be effective. The most effective method of sealing a brick veneer wall is to install a watertight seal behind the brick when the building is constructed. To flood proof existing brick veneer structures, the best way to seal a wall is to add an additional layer of brick veneer with a seal “sandwiched” between the two layers. It is possible to apply a sealant to the outside of a brick, block, or concrete wall, but any coating must be applied carefully. Cement or asphalt-based coatings are the most effective materials for sealing such walls, while clear coatings such as epoxies and polyurethanes tend to be less effective. As a result, the esthetic advantages of brick veneer walls are lost with the use of better sealant coatings.

The difficulty and complexity of sealing a structure also depend on the type of foundation, since all structural joints, such as those where the walls meet foundations or slabs, require treatment. For very low flood levels, such as a few inches of water, a door can be flood proofed by installing a waterproof gasket and reinforcing the door jamb, hinge points, and latch or lockset and coating it with a waterproof paint or sealant.

If there is a chance of higher flood levels, some type of closure shield will be needed. If the expanse across the door is 3 feet or greater, the shield will have to be constructed of strong materials, such as heavy aluminum or steel plate. The frame for such an installation must be securely anchored into the structure. When windows are exposed to flooding, some form of protection is needed because standard plate glass cannot withstand flood forces. One solution is to brick up all or part of the windows. It may also be possible to use glass block over the windows instead of brick, to admit light. For normal-sized windows, shields can also be used. They should be made of such materials as strong Plexiglas, aluminum, or framed exterior plywood. These can be screwed to the building or slid into predesigned frame slots in order to cover the windows. Another alternative is to replace the glass with heavy Plexiglas; however, the window must be sealed shut and waterproofed using water-resistant caulking.

WET FLOOD PROOFING. If dry flood proofing is impossible or too costly, another option is wet flood proofing, which allows the structure to flood inside while ensuring there is minimal damage to the building and any contents. Interior flooding allows hydrostatic force on the inside of the building walls to equally counteract the hydrostatic force on the outside, thus eliminating the chance of structural damage. When the structure is designed for wet flood proofing, vulnerable items such as utilities, appliances, and furnaces should be relocated or temporarily waterproofed with plastic bags and sheeting. Utilities and appliances should be moved permanently or temporarily to a place in the building that is higher than a selected flood level--either to an existing area, such as the attic, or to a small addition that could serve as a utility room.

If there is no space for relocating utilities, appliances, and other contents, they may be protected in place. In the case of very shallow flooding, a mini-floodwall built around these items would provide protection. For deeper waters, they could be elevated on platforms or suspended overhead from floor or ceiling joists.

The property owner must have sufficient warning time to employ wet flood proofing methods by temporarily moving items and then to evacuate all personnel prior to flooding. If a building is subject to flash floods, this method will not work. In addition, the property owner must be aware that flooding an area containing a source of electricity or hazardous materials can be dangerous. Also, cleanup will be required after each flood.

The owner of a building that has been wet flood proofed may choose to flood the basement of that building with a clean, potable water source (such as water from a garden hose connected to a faucet) before floodwaters reach the building. This would reduce the amount of contaminated floodwaters entering the structure and would minimize health concerns, cleanup time, and costs.

CHARACTERISTIC ASSESSMENT FOR SUCCESSFUL FLOOD PROOFING

FLOODING CHARACTERISTICS.

Flood Depth. A structure is susceptible to floods of various depths, with floods of greater depth occurring less frequently than floods of lesser depths. Potential flood elevations from significant flooding sources are shown in flood insurance studies (FIS) for communities participating in the National Flood Insurance Program (NFIP) and in other sources of flood plain information. For the purpose of assessing the depth of flooding likely to impact a structure, it is convenient to use the flood levels shown in FIS's, historical flood levels, and/or flood information from other studies and reports. The depth of flooding affecting a structure can be calculated by determining the height of the flood above the ground elevation at the site of the structure.

If a structure such as a building is subject to flooding depths greater than 3 feet, elevating or relocating the structure are the most effective measures of flood proofing. Dry flood proofing is not appropriate because water depths greater than 3 feet may cause hydrostatic force large enough to render structural damage or cause wall collapse unless the building has been designed to accommodate such forces. Flood proofing with levees and floodwalls for depths greater than 3 feet can be undertaken, but it may require devices to control seepage under the levee or floodwall.

If a structure subject to flooding depths less than 3 feet is well constructed by conventional methods, hydrostatic force is not a problem. Therefore, consideration can be given to using barriers, sealants, and closures for flood proofing. If shallow flooding causes a basement to fill with water, wet flood proofing can be used to reduce flood damage. Special devices are available to prevent basement flooding due to water backup through sewers.

Flood Velocity. The speed at which floodwaters move--the floodflow velocity-- is normally expressed in terms of feet per second (fps). As floodwater velocity increases, hydrodynamic forces are added to the hydrostatic forces from the depth of still water, significantly increasing the possibility of structure failure. Greater velocities can quickly erode or scour the soil surrounding structures. These fast-moving waters can also result in failure by erosion, and their impact may move a structure from its foundation. When floodwater velocities exceed 3 fps and 3 feet of depth, it becomes difficult, if not impossible, for adults to maintain their balance while walking through a flooded area. Unfortunately, there is usually no readily available source of information to determine potential flood velocities in the vicinity of specific structures. Historical information from past flood events is probably the most reliable source. If personal knowledge of past flood erosion and/or movement of structures is not available, others in the neighborhood may be able to provide this type of information. If specific information on flood velocities is available and indicates that the structure is subject to floodwaters with velocities greater than 3 fps, professional advice is critical in the selection of an appropriate flood proofing measure.

Flash Flooding. In areas of steep topography and/or small drainage areas, floodwaters can rise very quickly with little or no warning. This condition is known as flash flooding. High velocities usually accompany flash flooding and may preclude certain types of flood proofing. In a flash flooding situation, flooding usually begins to occur within 1 hour after significant rainfall. If a structure is susceptible to flash floods, insufficient warning time can preclude the use of any flood proofing method requiring human intervention, such as installing closures on windows, doors, or floodwalls. Temporarily relocating moveable contents to a higher level is also impractical. However, these methods can be effective if a building is not subject to flash flooding and the area has an adequate flood warning system and such warnings are broadcast on television and radio or disseminated on a personal basis by local emergency authorities. In areas of long-duration flooding, certain methods such as dry flood proofing may not be as applicable because of the increased chance for seepage and failure due to prolonged exposure to floodwater.

Ice and Debris Flow. In colder climates, chunks of ice from ice breakup can be carried in floodwaters and act as a battering ram, causing serious structure damage. During flood periods with freezing temperatures, ice can also form around the structure. If floodwaters rise and the ice is thick enough and attached well enough to the structure, lifting can occur, causing severe damage. Floodwaters often carry debris, such as boulders, rocks, and trees, that can destroy most flood proofing measures as well as the structure itself. This type of floodflow is called a mudflow, debris flow, or a mudflood, depending on the quantity of sediment/debris in the floodwater.

If a structure is subject to ice or mudflow/debris flow, flood proofing measures involving elevation other than on earthen fill require the services of a professional engineer to ensure that the building structural supports can withstand the impact of ice or debris flow. Dry flood proofing and wet flood proofing measures should not be used if the building is in an area of ice and debris flow. Floodwalls or levees can be used to protect against this type of hazard if properly designed. Relocation is always applicable for mitigating this type of hazard.

SITE CHARACTERISTICS.

Site Location. Coastal flooding is normally caused by such large storms as hurricanes that cause hazards due to waves, storm surge, abnormally high tides, heavy rainfall, beach erosion, etc. Normally, plenty of warning time exists. High tides, coupled with wave action from high winds, often cause damage more severe than that brought on by river or lake flooding. If a structure is subject to coastal flooding, elevation on piles or posts (preferably piles) or relocation are the only feasible flood proofing measures. The destructive force of wave action will generally destroy other types of flood proofing.

Riverine flooding results from heavy or prolonged rainfall, snowmelt, or combined runoff from the drainage area. Hazards from riverine flooding are based on flood depth, flood duration, flood velocity, erosion, and ice and debris. Warning time can vary from minutes to weeks.

Depending on the characteristic of the flooding source and flood, all flood proofing measures are applicable.

Soil Type. Permeable soils, such as sand, are those that allow groundwater to flow freely. If a structure such as a building has a basement and is located on permeable soil, flood proofing measures involving sealants and closures are ineffective because the permeable soil will allow groundwater to increase hydrostatic force on the basement walls, causing seepage and/or structural damage. Water will pass under floodwalls and levees constructed on permeable soil unless seepage control measures are included as part of the flood proofing measure. Other problems with soil that is saturated with floodwaters also need to be considered. If a structure is located on unconsolidated soil, wetting of the soil may cause uneven (differential) settlement. The structure may then be damaged by inadequate support and pulling or bending forces. Some soils may expand when exposed to floodwater and cause forces against basement walls and floors. Thus, serious damage can occur even though floodwaters do not enter the structures.

STRUCTURE CHARACTERISTICS.

Structure Foundation. There are three basic types of foundations for structures such as buildings which may be utilized individually or in various combinations. They are slab-on-grade; crawl space with the structure supported on extended foundation walls, piers, posts (columns), or piles; and basements with poured concrete walls and floors or masonry walls and poured concrete floors. Each type of foundation has its own advantages and limitations when flood proofing measures are being evaluated. All types of flood proofing can be considered for slab-on-grade foundations and crawl spaces on extended foundation walls. However, the crawl space foundation generally provides for more economical elevation and relocation flood proofing measures. Structures with basements require more involved flood proofing measures and are generally not recommended for flood proofing.

<u>Structure Construction</u>. Most structures are constructed of concrete and masonry or wood. However, other materials such as steel, aluminum, vinyl, and fiberglass are also used. Combinations of these materials may be used in the construction of a single structure. Thus, the suitability of applying a specific flood proofing measure can be difficult to assess. Concrete and masonry construction can be considered for all types of flood proofing measures. When classifying construction as concrete and masonry, it is important that all walls and foundations be constructed of the material. Otherwise, there may be a weak link in the flood proofing measure, resulting in potential for failure.

<u>Structure Condition</u>. Structure condition may not be easy to evaluate, as many structural defects are not readily apparent. However, careful inspection of the property should provide for a classification of "excellent to good" or "fair to poor." This classification is only for the reconnaissance phase of selecting an appropriate flood proofing measure(s). More in-depth investigation and design may alter the initial judgment regarding building condition and eliminate consideration of some flood proofing measures.

FLOOD PROOFING MATRIX

A flood proofing matrix (Figure 1) has been included in this report to better understand the relationship of flood characteristics, site characteristics, and structure characteristics to the applicability of particular flood proofing measures. The matrix serves to summarize the information presented in this chapter.

Instructions for using the
FLOOD PROOFING MATRIX

STEP 1 Select the appropriate row for each of the nine characteristics that best reflects the flooding, site, and building structure characteristics.

STEP 2 Circle the N/A (not applicable) boxes in the rows of characteristics selected.

STEP 3 Examine each column representing the different flood proofing measures. If one or more N/A boxes are circled in a column representing a flood proofing measure, that alternative should be eliminated from consideration unless special features (as footnoted) are applied to overcome the N/A concern.

STEP 4 Test the flood proofing measures that do not have circled N/A boxes for compliance with your community's flood plain management ordinance and building permit requirements.

STEP 5 Flood proofing measures that would be in compliance with community requirements should now be further evaluated for economic, aesthetic, risk, and other considerations. A preferred measure should evolve from this evaluation.

STEP 6 Obtain professional engineering and construction services for detailed design and implementation of the preferred flood proofing measure. Professional advice may rule out the preferred measure, and an alternate measure will need to be selected.

N/A[2] Dry flood proofing can work with these depths if the walls and floor are designed to resist the hydrostatic force and if the structure is designed to not become buoyant.

N/A[3] Space and aesthetics usually limit levee and floodwall heights for flood proofing to 6 feet. However, from an engineering viewpoint, greater heights are common.

N/A[4] Hydrodynamic force directly on the structure eliminates this measure.

N/A[5] Scour due to fast flood velocity eliminates this measure.

N/A[6] Flash flooding does not allow time for human intervention; thus, these measures must perform without human activity involved. Openings in foundation walls must be large enough to equalize water forces and should not have removable covers. Closures and shields must be permanently in place, and wet flood proofing cannot include last-minute modifications.

N/A[7] Permeable soils allow seepage under floodwalls and levees; therefore, some type of cutoff feature would be needed beneath structures. Permeable soils also allow hydrostatic force to directly affect the structure; therefore, the walls and floor must be designed to resist hydrostatic force and buoyancy.

FLOOD PROOFING MATRIX

		FLOOD PROOFING MEASURES									
		Elevation on Foundation Walls	Elevation on Piers	Elevation on Posts or Columns	Elevation on Piles[1]	Elevation on Fill[1]	Relocation	Floodwalls and Levees	Floodwalls and Levees with Closures	Dry Flood Proofing	Wet Flood Proofing
FLOODING CHARACTERISTICS	**Flood Depth**										
	Shallow (less than 3 feet)										
	Moderate (3 to 6 feet)									N/A[1]	
	Deep (greater than 6 feet)							N/A[2]	N/A[2]	N/A[1]	
	Flood Velocity										
	Slow (less than 3 fps)										
	Moderate (3 to 5 fps)	N/A[3]								N/A[3]	N/A[3]
	Fast (greater than 5 fps)	N/A[3/4]	N/A[4]							N/A[3/4]	N/A[3/4]
	Flash Flooding										
	Yes (less than 1 hour)								N/A[5]	N/A[5]	N/A[5]
	No										
	Ice and Debris Flow										
	Yes	N/A								N/A	N/A
	No										
SITE CHARAC-TERISTICS	**Site Location**										
	Coastal Floodplain	N/A	N/A					N/A	N/A	N/A	N/A
	Riverine Floodplain										
	Soil Type										
	Permeable							N/A[6]	N/A[6]	N/A[6]	
	Impermeable										
BUILDING CHARACTERISTICS	**Building Foundation**										
	Slab on Grade										
	Crawl Space									N/A	
	Basement		N/A	N/A	N/A					N/A	
	Building Construction										
	Concrete or Masonary										
	Metal										
	Wood										N/A
	Building Condition										
	Excellent to Good										
	Fair to Poor	N/A	N/A	N/A	N/A	N/A	N/A			N/A	N/A

1> For an existing structure, the structure must be temporarily relocated to place fill and piles